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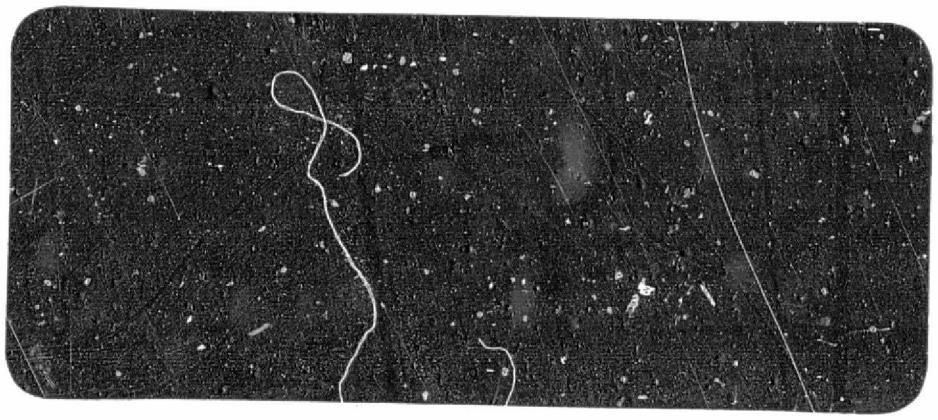

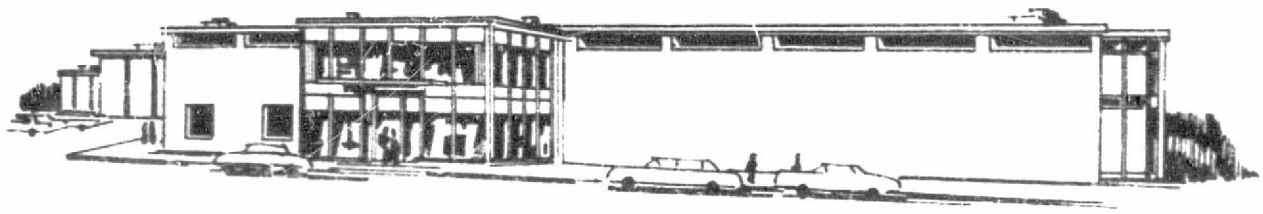

Putting Materials Together Through Chemistry and Mechanical Design

G. T. Schjeldahl Company
Northfield, Minnesota

September 1, 1964

FINAL REPORT

THE EFFECTS OF HIGH VACUUM AND ULTRAVIOLET RADIATION ON PLASTIC MATERIAL

Mod 1

Contract NAS5-2834

Modification I

Submitted To

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
WASHINGTON, D.C.

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ABSTRACT

This study is concerned with the following goals set forth in a letter of September 16, 1963, from F. H. Bratton to Mrs. Edith C. Hall.

1. Investigate methods for heating and deforming the exposed plastic in advanced materials to reduce or eliminate subsequent shrinkage.
2. Evaluate a continuous process for chemically milling a 90 per cent open material.
3. Determine the effects of simulated space conditions on several types of advanced materials.

It is the purpose of this report to summarize the results of this study.

Heat and deform tests were made using several methods. It was found that bulging the plastic in relation to the aluminum web was difficult to achieve without losing its material strength.

Chemical milling runs were made evaluating various resists and etchants. A process was developed using a copper chloride etchant which will mill a 90 per cent open pattern in 4-mil aluminum.

Experiments performed in a solar simulator indicate that both heat treatment and an initial exposure in a restrained condition improve the ability of polypropylene and Mylar to withstand the conditions of outer space.

Heat treated Mylar exposed for 50 days shrunk 2.78 per cent after being given an initial radiation exposure in a restrained condition.

Polypropylene retracted 4.4 per cent in the direction of restraint and considerably more in lateral direction in which it was not initially restrained.

Thermal values were determined and theoretical balloon temperatures were calculated for the materials that were exposed to solar radiation for 50 days.

A hot spot temperature of 15° C was calculated for the plastic portion of the polypropylene sample with a 4 mil thick aluminum web which was 90 per cent milled. The calculated hot spot temperature for a similar material of Mylar was 84° C.

The results indicate that the optical degradation of polypropylene is much less than previously predicted. Based on these results a satellite constructed of polypropylene will not be damaged by overheating in an outer space environment.

NEW TECHNOLOGY

Electroless Nickel Resist

Early in the program a search was made to find a resist that would withstand the action of caustic soda. Electroless nickel was suggested because of its excellent caustic resistance. The proposed process consisted of the following steps.

1. Print pattern with acid resisting lacquer
2. Electroless plate
3. Remove acid resisting lacquer
4. Chemically mill the exposed aluminum with caustic soda.

Samples of advanced material were nickel-plated in the laboratory using Enplate Ni-410, a product by Enthone, Inc. The procedure included the following steps.

1. Emulsion cleaner 75 at room temperature for 10 to 60 seconds
2. Cold water spray rinse
3. Aluminum cleaner NS-35 at 120-140°F for 30 seconds to 5 minutes
4. Cold water rinse
5. 75 per cent nitric acid with 1/2 to 1/4 ounce/gallon Acetone 70 at room temperature for 15 - 30 seconds to remove silicates.
6. Alumon 4.5 ounce/gallon at 60 - 70° F about 5 to 8 seconds using the double dip method
7. Enplate Ni-410, 2 parts A plus 1 part B plus 13 parts water

8. Cold water rinse

9. Dry.

Adhesion of the nickel to the aluminum was a problem at first; however, this was improved by applying alumon zincate by the double dip method rather than Alumon D.

Electroless nickel is quite brittle and it makes the laminate system quite rigid when deposited in a continuous film. However, when it is applied in a 90 per cent open pattern the laminate retains much of its flexibility. If the nickel is allowed to remain on the aluminum web, it improves the sphere rigidity of the material.

Cupric Chloride Etchant

A search was made to find an etchant that could be used with conventional resists that could be printed by commercial rotogravure methods. Although the use of cupric chloride for etching aluminum is described in the literature, it made a vast improvement and is considered as new technology as applied to the chemical milling of advanced material. A 90 per cent open pattern was milled in 4 mil thick aluminum with very little undercutting. Prior to this the optimum capability was a 73 per cent open pattern in an 0.5 mil thickness.

The etchant contains the following chemicals. It is used at room temperature.

1.67 pounds cupric chloride

2.50 gallons water

0.50 gallon hydrochloric acid

The etchant will mill through 4 mil thick aluminum in approximately 3 minutes.

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I. SUMMARY

Heat and Deform Tests

Experiments were performed to attempt to bulge the exposed plastic in relation to the aluminum web in advanced materials. The methods used were (1) hot air jet; (2) hot solder wave; and, (3) hot glycerine.

Although some evidence of bulging was obtained with the hot air jet, the material was found to retain only 1/5 of its original strength.

It is felt that a successful heat and deform process would require an extended development program and in the end require elaborate equipment with very close control.

Chemically Milling

Evaluation of a continuous printing process used for flexible printed circuits was made using several different resists. Line definition and elimination of a thin film of resist from the aluminum to be etched were the major problems encountered.

The resist that printed the best did not withstand the 25 per cent caustic soda until the 2-mil aluminum was etched away.

The answer to this problem was found to be a copper chloride etching solution which milled through 4-mil thick aluminum leaving the resist intact. Several resists were tested. Each worked equally well allowing a wider choice for a resist with the proper printing characteristics.

The 90 per cent open pattern was accomplished with very little undercutting.

Exposure to Simulated Solar Radiation

The exploratory study and the 50-day test indicate that both heat treatment and an initial exposure to space conditions in a restrained condition improve the ability of both Mylar and polypropylene to withstand the conditions of outer space.

Although heat treated Mylar showed no shrinkage for short exposures, under the conditions of the 50-day test it shrank 2.78 per cent. Samples of the same material which were placed in the chamber but which were not exposed to radiation shrank 0.33 per cent.

An exposure of 53 hours indicated that the 4-mil thick aluminum web was adequate to restrain polypropylene from shrinking providing the material was adequately restrained during an initial radiation treatment. This was substantiated in the 50-day test. The material shrank about 4.4 per cent in the direction in which it was restrained but considerably more in the lateral unrestrained direction. The back side of the polypropylene sample band being conditioned by reduced doses of radiation filtering through the front portion of the sample withstood the full amount of radiation for most of the exposure with minimum shrinkage.

The 4-mil aluminum web furnished enough restraint that holes appeared in the polypropylene windows as the plastic degraded.

Thermocouple readings indicated that the 50-day test ran at a higher temperature than previous exploratory runs.

The tensile strength of both Mylar and polypropylene dropped progressively as they were exposed to increasing amounts of radiation.

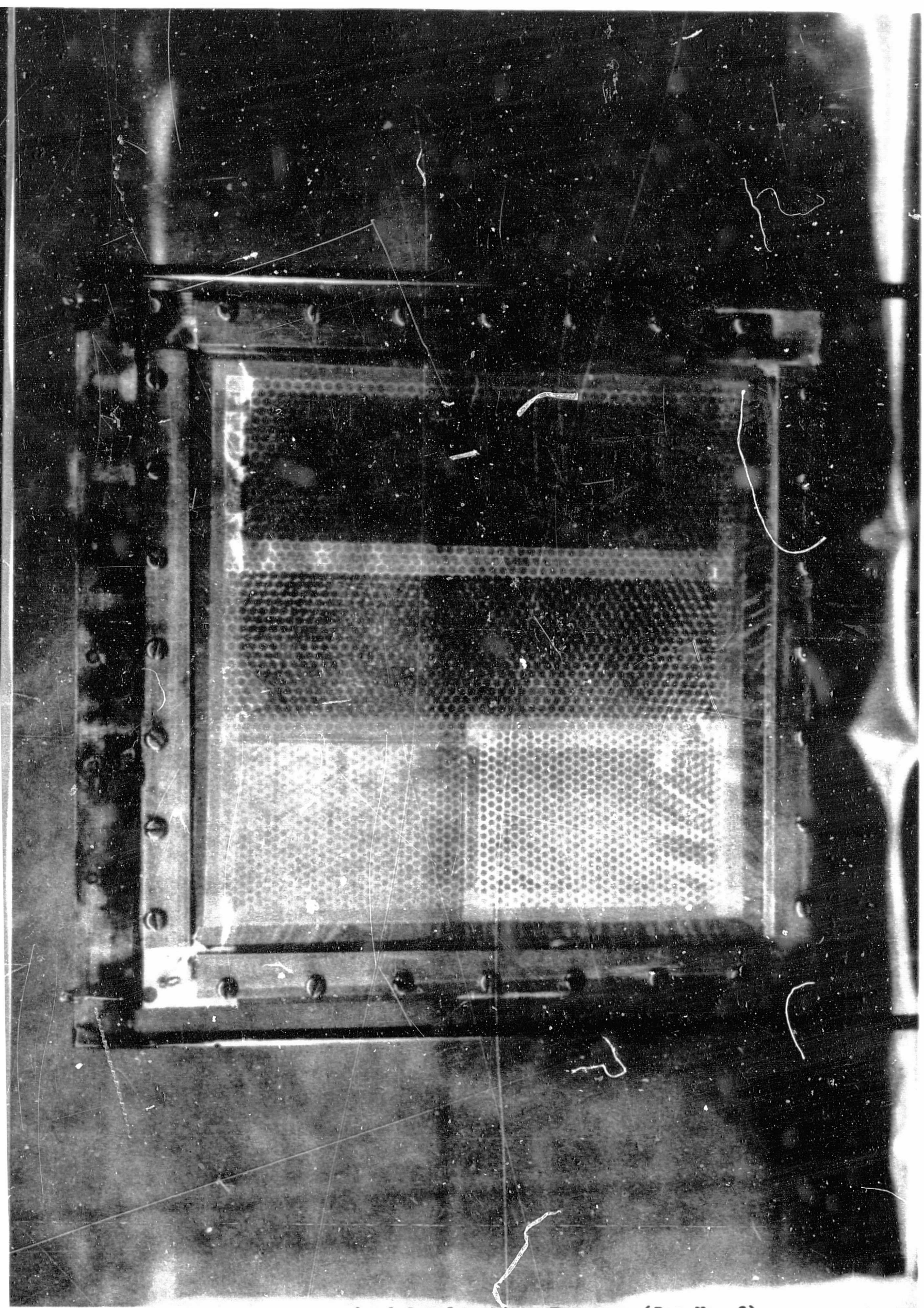
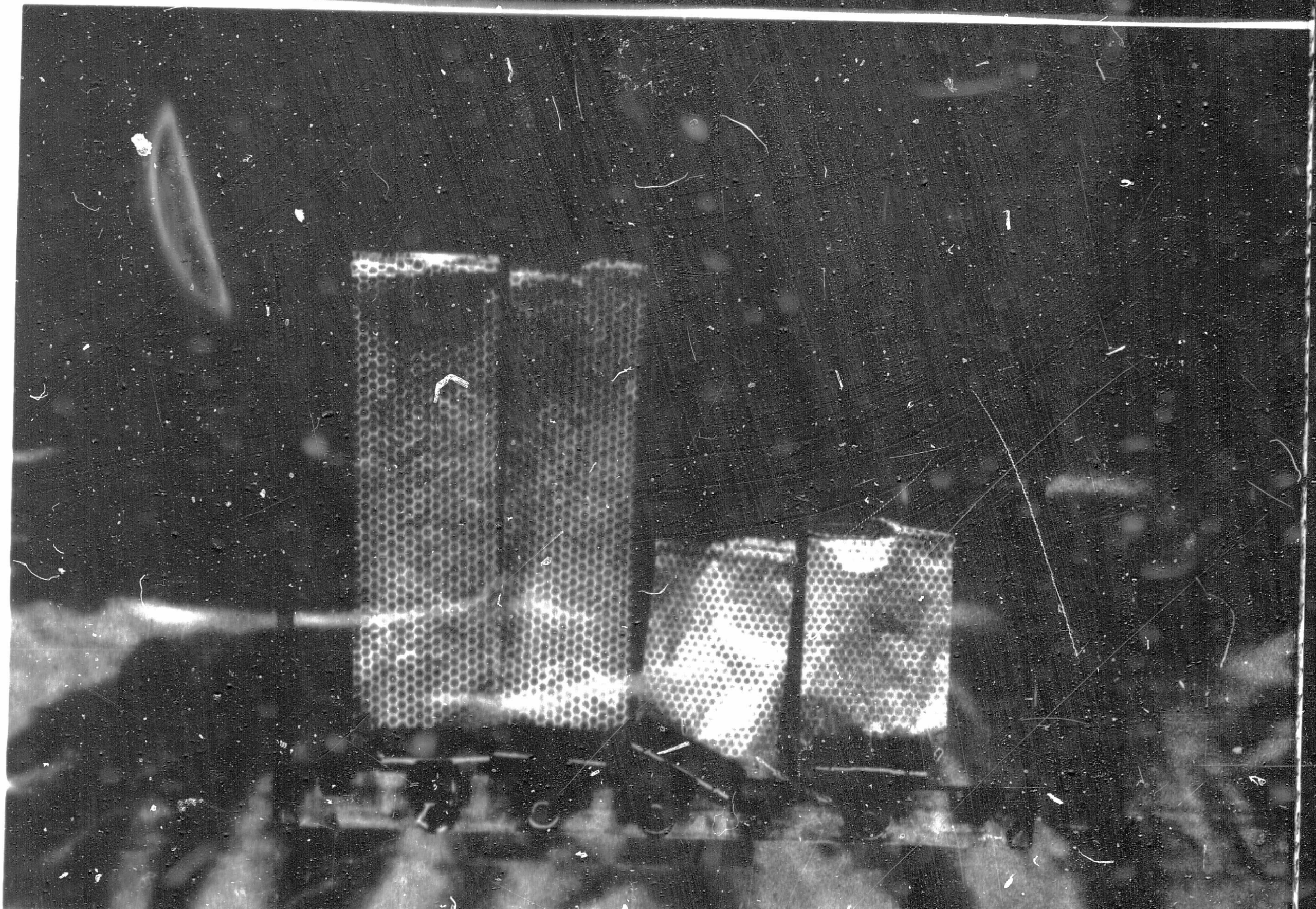


Figure 5. Restrained Samples After Exposure (Run No. 2)

The optical properties were measured for the samples that were exposed for 30 days. Thermal values were calculated and theoretical balloon temperatures were determined. The mean effective radiant temperature and the hot spot temperature for polypropylene ran considerably lower than those for Mylar.

Results indicate that the optical degradation of polypropylene when exposed to solar radiation is much less than previously predicted. Based on calculated hot spot temperatures a polypropylene balloon will not be damaged by overheating in the environment of outer space.



II. HEAT AND DEFORM TESTS

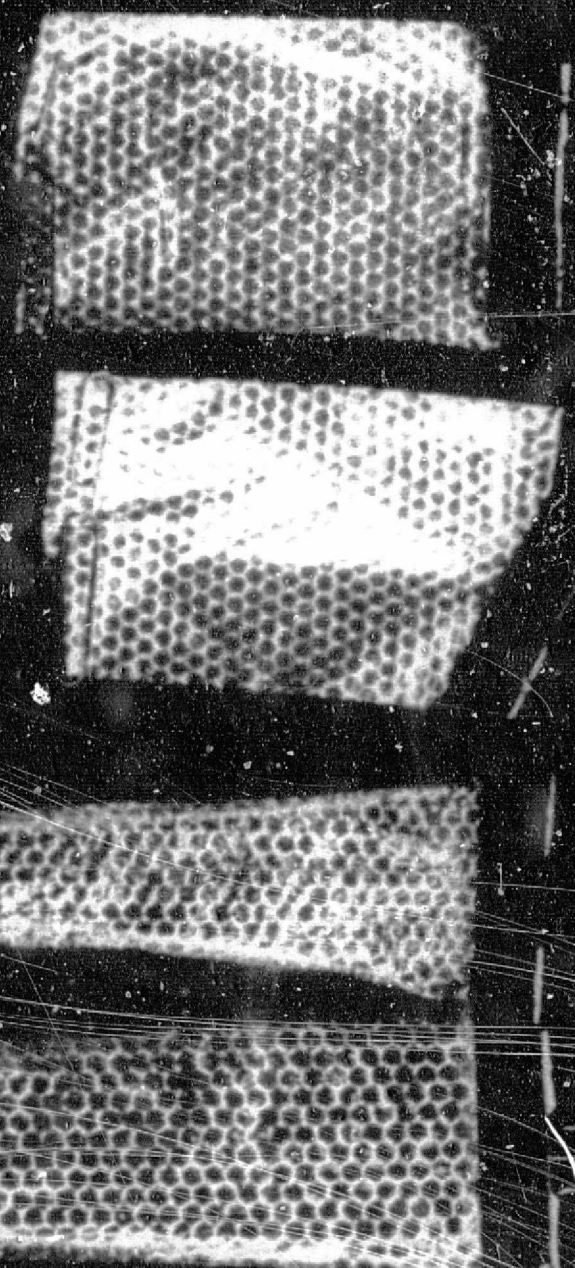
Samples of polypropylene and Mylar advanced material were simultaneously heated and deformed in an attempt to bulge the plastic film with respect to the aluminum mesh to reduce subsequent shrinkage. The following three methods were used.

A. Hot Air Jet

Polypropylene advanced material was restrained on large mesh wire screen with masking tape. A small air welder used to assemble polyvinyl chloride tubing was used as the hot air source. The force of the air jet was controlled by an air flowmeter and the temperature of the air was regulated with a variac. The air jet temperature giving the optimum results varied from 290 F at 1/6 inch from the nozzle to about 250 F at a distance of one inch.

The jet of air was carefully directed against the plastic to avoid rupturing the film. This required close control and it was found that the film had to be deformed several times before permanent bulging occurred. The material took on a cloudy appearance and appeared to actually melt before bulging could be obtained. In many instances the film would rupture before the film could be permanently bulged.

A sample of the treated material was tested for tensile strength and it was compared to untreated material. The thermally bulged material retained only 1/5 of the tensile strength of the original material.



B. Hot Solder Wave

Mylar advanced material was used in this test because of the high solder temperature.

The sample was restrained with tape in a small aluminum frame and placed plastic side down in the small lab solder machine. The chain drive was started which carried the sample over the solder wave. Several runs were made varying the temperature of the solder from its melting point to the melting point of the Mylar. No evidence of bulging or deformation was observed.

In the tests that were made the solder adhered to the Mylar. However, this can probably be eliminated by installing a shelf for the solder wave which will prevent the solder from forming icicles.

C. Hot Glycerine

Polypropylene advanced material was restrained on a piece of large mesh wire screen with tape in much the same way as the hot air jet method. Glycerine in a one-gallon container was brought to 120 C after which the sample was immersed and moved back and forth vigorously. The sample was removed periodically for evidence of bulging while the temperature was gradually increased. The test was stopped after reaching 170 C because the polypropylene lost much of its tensile strength above this point. No evidence of bulging was observed using this method; however, a pressurized jet of glycerine may be worth further study.

III. CHEMICAL MILLING

This investigation was undertaken to extend the previous work described in the report Heat Stabilization Study of Advanced Materials and to evaluate a new flexible circuit printing process when used to print a 90 per cent open pattern.

A roller was made to print the 90 per cent open pattern with a 0.15-inch square opening and a 0.006-inch line width. This was accomplished by machining ink carrying grooves into the face of the printing roller.

A 4-inch wide laminate of 25-gauge Mylar and 2-mil aluminum on one side was prepared.

The first printing was made using Naz-Dar No. 205, the blue ink which was found to give optimum results in the work done previously. Difficulty was experienced in printing a sharp, continuous transverse line and in keeping the resist from filling in the areas between the lines with a thin film of resist. A Teflon doctor blade was installed to wipe the excess ink from the roller in an effort to eliminate the haze. It was partially successful. Several runs were made varying the viscosity of the ink, the pressure between the roller and laminate, and the speed of printing. Results were unsatisfactory because line detail had to be sacrificed to eliminate the thin film of resist on the exposed aluminum.

A yellow resist ink EY214 made by the Menasha Printing Co. and which was also used in the previous investigation was tried next.

Although the same problems were encountered it was possible to get a sharp continuous transverse line with a minimum of haze in the areas between the lines.

This material was etched in the PVC laboratory scale etcher using a 25 per cent solution of sodium hydroxide. The resist deteriorated before the 2-mil aluminum could be etched through. The thickness of the resist material deposited by the printing process was considerably thinner than that obtained from the silk screen process in the previous study. A very slow machine speed in the etcher was necessary because of the relatively long etching time of approximately 20 minutes. It was found that the rate of feed at these slow machine speeds could not be controlled accurately enough to get a uniform etch.

The results indicated that the solution to the problem was a closer control on the machine speed with either a more durable resist or a different etchant. In a search for a more durable resist investigation was made into the possible use of electroless nickel to resist the caustic soda etchant. The proposed process included the following steps.

1. Print pattern with acid resisting lacquer.
2. Electroless plate.
3. Remove acid resisting lacquer.
4. Chemically mill the exposed aluminum with caustic soda.

Samples of X-32-F material were nickel-plated in the laboratory which withstood the action of the caustic soda while the exposed aluminum was etched through.

Adhesion of the nickel to the aluminum was a problem at first; however, this was corrected by using a different activator which resulted in a thinner Zincate coating.

Electroless nickel is quite brittle and it makes the laminate system quite rigid and easily cracked when deposited in a continuous film. However when the electroless nickel is deposited in a 90 per cent open pattern the laminate regains much of its flexibility. If the nickel is allowed to remain on the aluminum web, it improves the rigidity of the material.

A search was also made to find an etchant which would not attack conventional resists available for rotogravure printing. The following copper chloride solution provided a significant breakthrough and furnished us with a method for 90 per cent milling through very thick aluminum foil.

1.67 lb $CuCl_2$

2.50 gal water

.50 gal HCl

The etching was carried out in a frame-type etcher with the solution at room temperature. The reaction generated no fumes as the caustic soda did previously. The new etching solution milled a 90 per cent open pattern in 4-mil thick aluminum in approximately three minutes. Several conventional resists were evaluated using the copper chloride solution. It was found that all the resists tested withstood the etchant while the 4-mil aluminum was milled away. The milling was accomplished with very little undercutting.

The reaction of the $CuCl_2$ with the aluminum produced a metallic copper sponge. This would have to be removed by suitable means in a future production-size operation to prevent pump fouling. The process appears to be more compatible to large-scale operation than the previous caustic soda process however, because of the use of milder chemicals, the absence of fumes and operation at room temperature.

IV. EXPOSURE OF ADVANCED MATERIAL TO SIMULATED SPACE CONDITIONS

The Heat Stabilization Study of Advanced Materials made under Modification 3 of Contract NAS5-2834 described the effects of heat on polypropylene and Mylar under conditions experienced at the earth's surface.

The present study now in progress under Modification I of contract NAS5-2834 will supplement the previous work and show the behavior of these materials under simulated space conditions.

Two solar simulator runs have been made to date and will be described in this report.

A. Equipment Description

1 - Varian high vacuum chamber Model 935-0006

1 - Genarco solar simulator Type ME-4

1 - 12 X 12-inch steel restraining frame

1 - 12 X 12-inch plate glass

1 - Steel sample stand

1 - Copper-constantan thermocouple wire

1 - Rubicon potentiometer

The Genarco solar simulator produced radiation with a continuous spectrum between 2,300 and 60,000 angstroms. Its spectral distribution, over this range, simulated closely that of the sun.

B. Sample Preparation

1. Polypropylene

A quantity of advanced material in the printed stage was

drawn from stock and it was identified as type X-32-F from the following measurements.

.35-mil aluminum

.1-mil adhesive thickness

.5-mil polypropylene

The resist pattern was removed from one side with solvent after which the sample strips were etched in 25 per cent caustic soda, leaving the aluminum web on one side. After milling, a sulphuric acid rinse was used to remove the resist and adhesive.

A portion of the samples was heat treated, before milling, in hot glycerine at 160 C for one minute.

2. Mylar

Samples of 70 per cent milled Mylar advanced material were heat treated at 160 C. There was evidence of small amounts of adhesive on the film. The laminate measured as follows:

.2-mil aluminum

.4-mil Mylar

C. Exploratory Runs

Run No. 1

The first run was made to find the problems involved in exposing advanced materials in the solar simulator and to determine the approximate magnitude of shrinkage caused by simulated space conditions.

The following 1-in by 10-in samples as shown left to right in

Figure 1 were placed in the vacuum chamber and exposed for eight hours.

102-11-A Unheat-treated X-32-D polypropylene suspended, unrestrained, about 1 inch in front of the plate of glass.

102-11-B Same material as 102-11-A except it was restrained on window glass with Permacel K-18 tape.

102-11-C Heat-treated X-15 (Mylar) suspended, unrestrained, about 1 inch in front of the glass with the aluminum away from the light.

102-11-D Sample of as-received Chemore Corporation polypropylene oriented in one direction only. It was suspended, unrestrained, about 1 inch in front of the glass.

A thermocouple wire was mounted between sample 102-11-B and the glass plate and connected to the potentiometer using the chamber wall feed-through.

Before the arc was started the pressure in the chamber was 10^{-8} torr. The pressure increased to 10^{-5} when the light was initially directed into the chamber, and it decreased gradually to 10^{-7} over the 8-hour run.

The temperature indicated by the thermocouple varied from 45 to 115 C. Temperature surges within this range were recorded when new electrodes were started and when "bell jar heat" was used.

The 8-hour exposure changed the samples considerably as shown left to right in Figure 2.

Figure 1
Samples Before Exposure (Run No. 1)

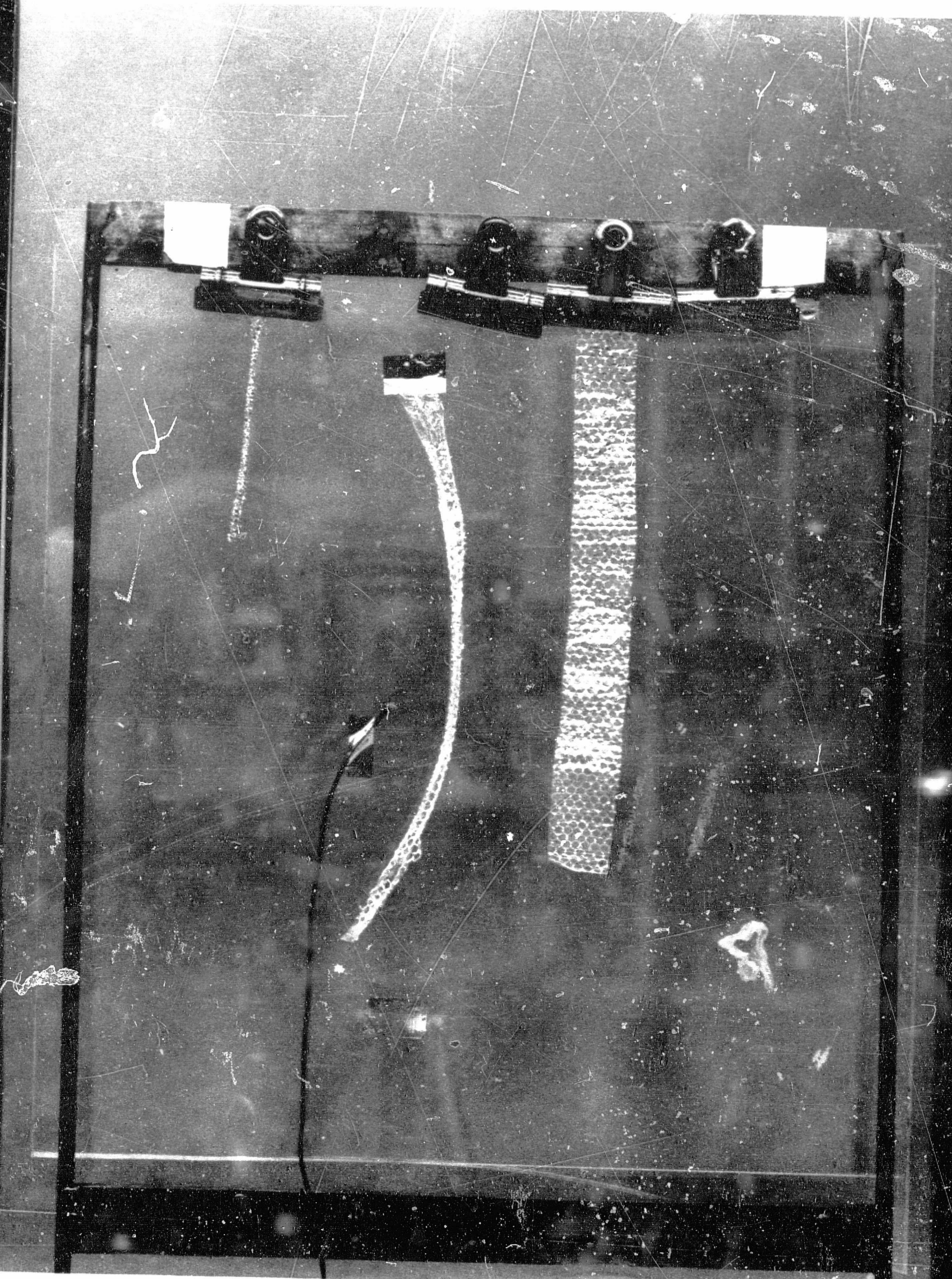


Figure 2
Samples After Exposure (Run No. 1)

102-16-1 (Upper left)	Heat-treated X-15 Mylar with the aluminum turned away from the light.
102-16-2 (Lower left)	Same as sample 102-16-1 except with the aluminum facing toward the light.
102-16-3 (Middle)	Unheat-treated X-32-F polypropylene with the aluminum toward the light.
102-16-4 (Right)	Heat-treated X-32-F polypropylene with the aluminum toward the light.

The thermocouple wire was mounted on sample 102-16-2 with tape. The tip of the thermocouple was exposed to the light and was pressing against the sample.

In Run No. 1 the sample of Mylar 102-11-C with the aluminum on the back side showed the most shrinkage in the plastic film directly beneath the aluminum web as if greater heat was concentrated at this point. In Run No. 2 the aluminum side on one of the Mylar samples was reversed to show, whether facing the aluminum away or toward the light, made a difference in shrinkage.

The polypropylene samples in Run No. 2 demonstrated the difference in shrinkage made by heat treating and also compared the effect of an initial, restrained, ultraviolet treatment to the unrestrained condition of Run No. 1.

The samples were exposed in the restraining frame (Figure 4) for a period of eight hours. During this time the pressure rose from an initial 2×10^{-8} to 3×10^{-6} torr and then dropped back to approximately 6×10^{-7} at the end of the run.

The indicated temperature in the restrained part of the run started at 87 C and leveled out at about 103 C. Twice, when new

Figure 4
Restrained Samples in Solar Simulator

electrodes were first started the temperature surged to 108 C and then dropped back to the normal 103 C high. "Bell jar heat" was not used in Run No. 2 which gave a more uniform temperature.

At the end of the restrained part of the run the samples appeared to be in good condition (Figure 5) although quite tightly stretched within the frame.

A description of the samples is given below.

Sample		Description
102-16-1 (Upper Left)	Mylar	Drawn taut but otherwise no change.
102-16-2 (Lower Left)	Mylar	Drawn taut but otherwise no change.
102-16-3 (Middle)	Polypropylene (Unheat-treated)	Drawn taut. Aluminum web was wrinkled as if the uncovered plastic had pulled in.
102-16-4 (Right)	Polypropylene (Heat-treated)	Drawn taut. Aluminum web was slightly wrinkled like sample 3 but much less.

After the initial exposure the samples were cut out of the taped assembly and measured. They were clipped to the steel stand (Figure 6), placed back into the chamber (Figure 7). They were exposed eight hours, each sample hanging unrestrained. The thermocouple wire was attached to sample 102-16-2 in the same manner as in the restrained part of the run.

Two paper clips were placed at the bottom of each sample to keep it hanging vertically.

The pressure varied bewteen 5×10^{-8} and 6×10^{-7} torr.

The temperature leveled out at about 117 C with surges recorded as high as 123 C.

During the exposure, the appearance of the samples was visually checked at frequent intervals. The only change that was observed was a gradual shrinking of sample 102-16-3 during the 8-hour exposure.

Localized shrinkage occurred on each sample where it was in contact with a paper clip or clamp which indicated that the temperature of the metal clips was considerably higher than that of the samples. The samples after the 8-hour, unrestrained run are shown in Figure 8.

Sample	Visual Description	Measured Shrinkage*
102-16-1 Mylar (Alum. away from light)	No change	0%
102-16-2 Mylar (Alum. facing light)	No change	0%
102-16-3 Polypropylene (Unheat-treated)	Definite retraction. Edges starting to curl.	8%
102-16-4 Polypropylene (Heat-treated)	Slight retraction. Aluminum web was wrinkled about the same degree as before the exposure.	2

*Note: The samples were measured, using a steel rule, to the nearest millimeter and the above shrinkages calculated.

Run No. 3

The object of this run was to inflate a small bag in simulated space conditions similar to those experienced by an actual communication satellite.

A 7-inch by 7-inch Mylar bag was fabricated from a 70 per cent milled aluminum-Mylar laminate. It was heat treated and the alumin was Alodine coated.

The bag was suspended in the chamber from a steel stand as shown in Figures 9 and 10. Before the chamber was pumped down the bag was evacuated with a mechanical pump to a pressure of 5 microns. The pump was then switched to the vacuum chamber. As the pressure in the chamber decreased, residual air in the bag started to inflate the bag. The residual air was released to the chamber by opening valve B, Figure 10. At a vacuum of approximately 10^{-6} torr valve B was closed and air was bled into the bag through valve A until it was fully inflated. After inflation the solar lamp was started and the bag was exposed for 24 hours. The bag remained inflated over this period and did not require reinflation.

After the inflated exposure period, valve B was opened slowly, releasing the pressure in the bag. It was noted at this point that the bag retained its shape and appeared quite rigid. Later when the bag was examined this was found to be due both to the strained aluminum and the tape used to fabricate the bag.

The bag was exposed in the deflated state for an additional eight hours. It retained its shape well.

With valve B fully open to keep from collapsing the bag, the chamber was brought slowly to atmospheric pressure. The chamber was opened and the bag was examined. The Alodine-coated heat-treate

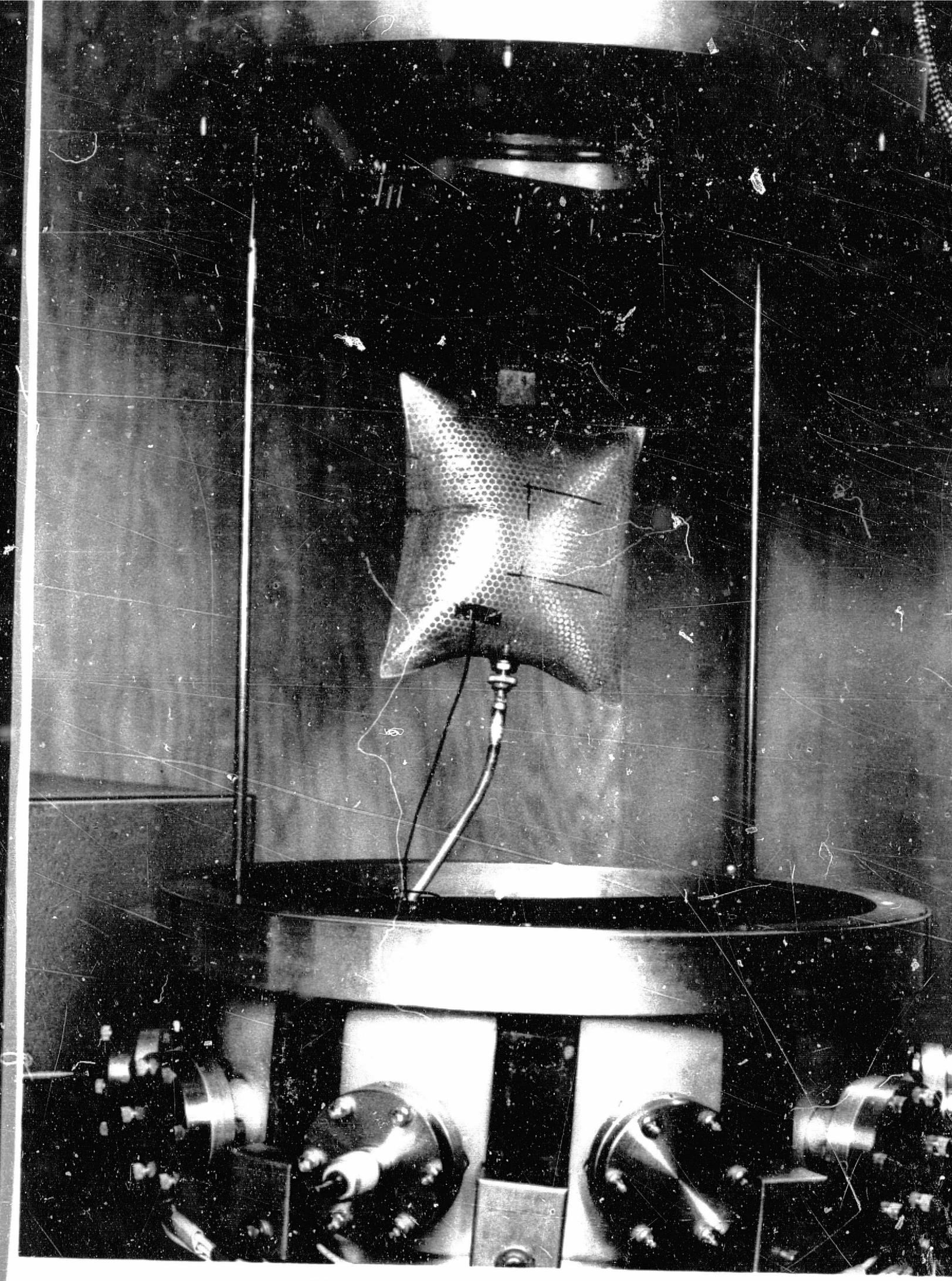
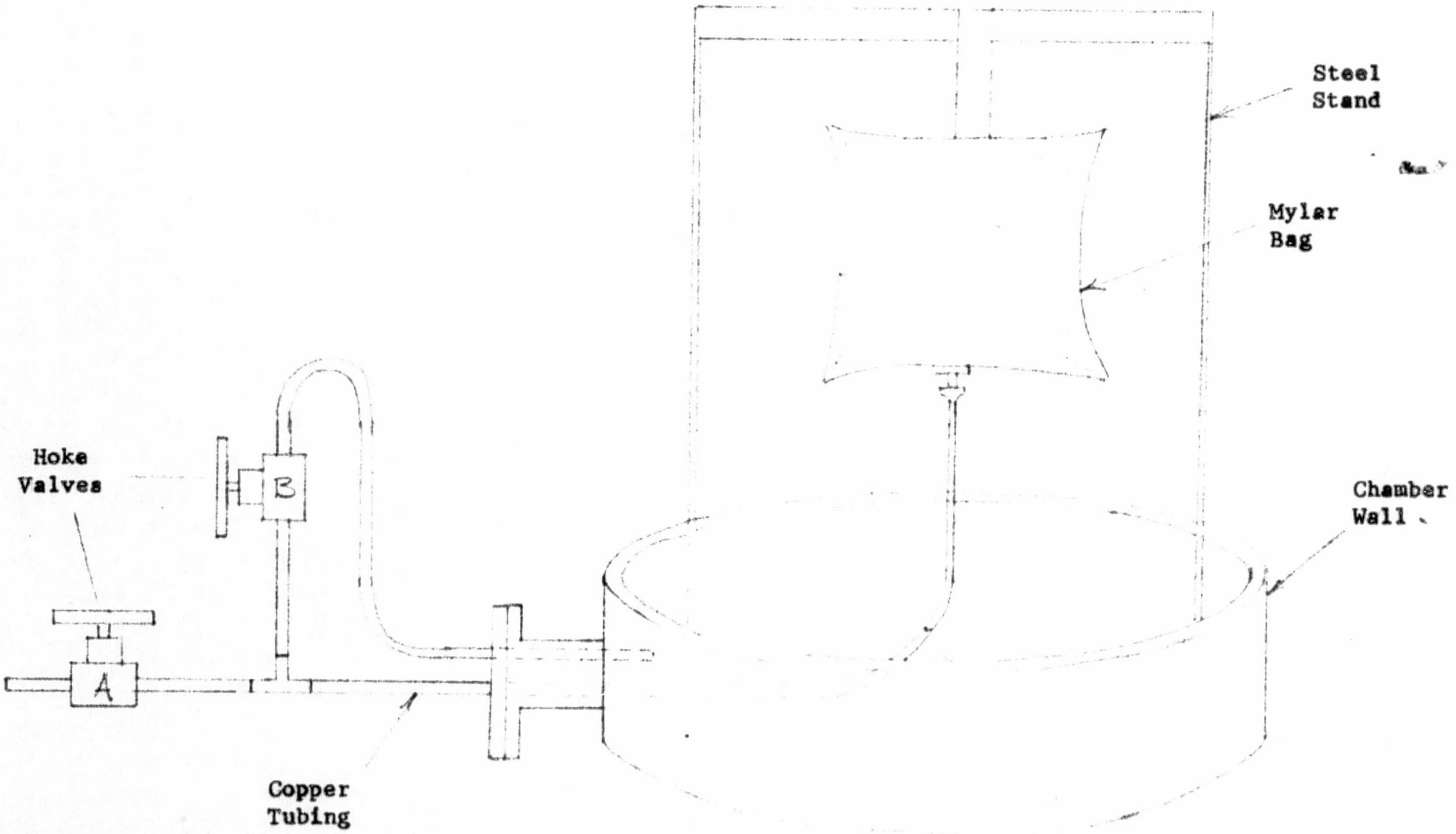


Figure 9. Inflated Balloon

Figure 10

Bag Inflation System



Mylar laminate appeared in good condition and it retained much of its flexibility.

The grid on the face of the bag was measured for shrinkage but none was detected with a steel rule measuring to the nearest 1/64-inch. The bag developed a slight amber cast. In Figure 11 the exposed bag is in the center. An unexposed bag is on the left.

Run No. 4

This run was similar to Run No. 3 with the exception that the bag was made of heat-treated X-32-F polypropylene advanced material.

During the inflated exposure period of this run the balloon had to be reinflated every two hours to maintain its shape due to the presence of a small leak.

A square grid was marked on the face of the bag with marking ink for later shrinkage measurements.

Although the polypropylene shrunk under the black ink marks, the measurement across the grid was greater after exposure. This was caused by over-inflation at the start which actually stretched the advanced material.

After exposure and deflation the bag maintained a good shape; however, this was due partially to the tape used to fabricate it. No discoloration was detected. The exposed bag is shown in Figure 11 on the right.

Run No. 5

The object of this run was to expose additional samples in a restraining frame similar to Run No. 2, except for longer exposure times.

The samples described below were taped together within a Mylar frame similar to Figure 3 to simulate the restrained conditions of an inflated balloon. They were exposed in the restrained condition for a 24-hour period, then removed from the chamber, cut out of the frame and exposed again in an unrestrained condition for a period of about thirty hours. The exposed samples are shown in Figure 12.

102-44-1 70 per cent milled, 2-mil aluminum/15-gauge Mylar unheat-treated, no Alodine. When compared to previously run heat-treated samples, the shrinkage that occurred in this sample indicates that heat treating Mylar increases its resistance to simulated space conditions.

102-44-2 "As received" 50-gauge Mylar. A spectral analysis of this material was made in the visible, near-ultraviolet range and its loss of transmission was compared to a sample that had been laminated, chemically milled and which carried traces of adhesive. The "as received" sample lost transmission ability with the exposure in a conventional manner. The processed laminate gained transmission ability as if the radiation and high vacuum were removing adhesive or other contaminates from the surface.

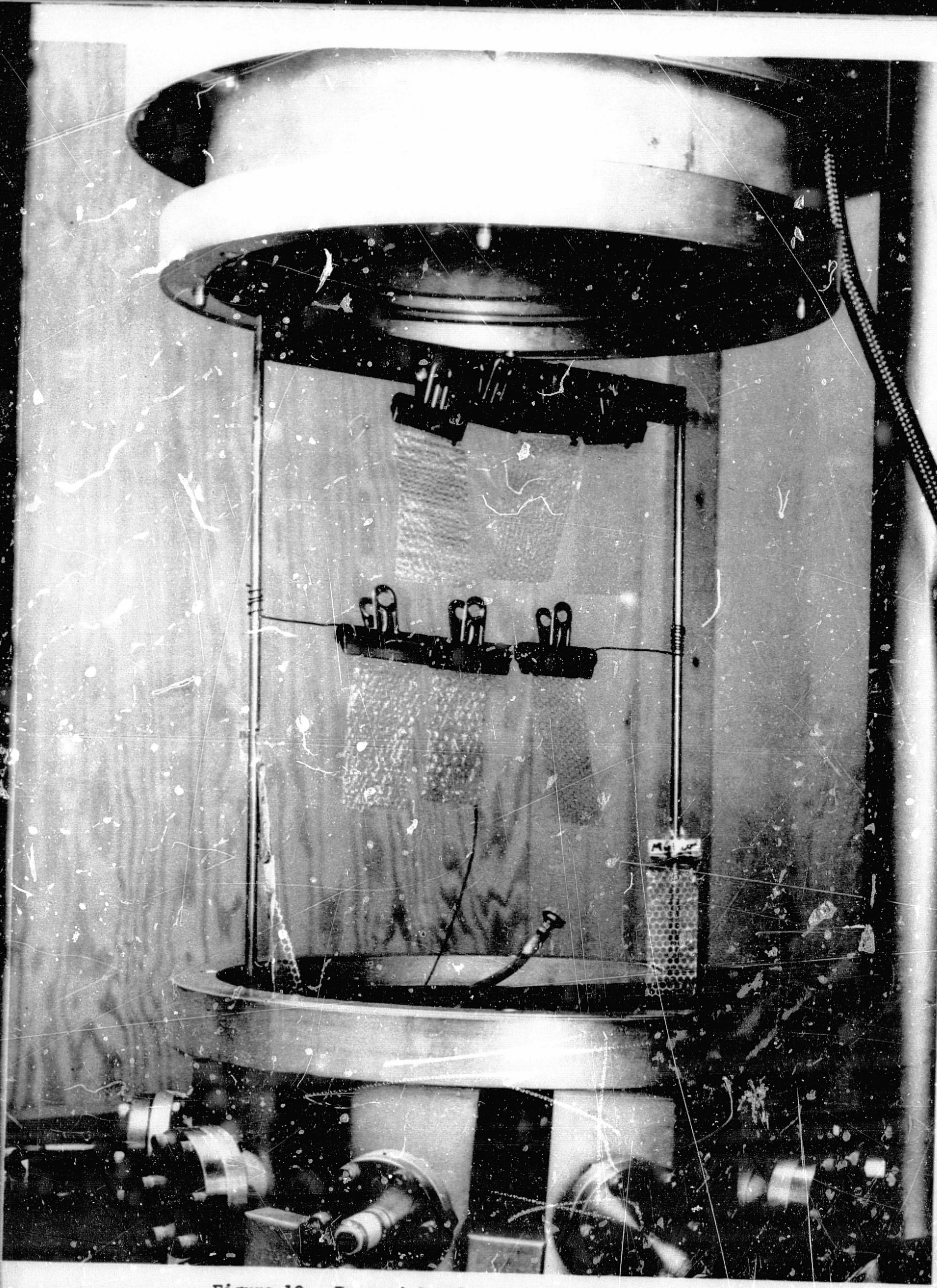


Figure 12. Exposed Samples (Run No. 5)

102-44-3 90 per cent milled, 2-mil aluminum/0.6-mil polypropylene heat-treated. This sample shrunk about 1.5 per cent indicating that the 2-mil aluminum does not have enough restraining power to prevent the plastic from shrinking.

102-44-4 90 per cent milled, 4-mil aluminum/0.6-mil polypropylene heat-treated. This sample had no measurable shrinkage, indicating that the 4-mil aluminum adequately restrained the polypropylene under the conditions of this exposure.

102-44-5 The same as 102-44-4 except unheat-treated. The sample shrunk about 11 per cent which indicates the 4-mil aluminum will not restrain unheat-treated polypropylene.

102-44-6 90 per cent milled, 4-mil aluminum/0.6-mil polypropylene unheat-treated, adhesive not removed. The sample shrunk 9 per cent which was about the same as without adhesive.

102-44-7 90 per cent milled, 2-mil aluminum/15-gauge Mylar unheat-treated. Placed in chamber in the shadow of the light. The 0.72 per cent shrinkage was measured microscopically to the nearest 0.001 inch.

102-44-8 X-32-F, polypropylene, heat-treated. This sample was also placed in the shadow of the light. Snrinkage was 0.36 per cent and was measured to the nearest 0.001 inch microscopically.

102-44-9 X-32-F, polypropylene, heat-treated. The sample was placed in the chamber for the unrestrained portion of the run only. Shrinkage was only 0.8 per cent indicating that heat

treating increases the ability of the material to resist the effects of space conditions.

Run No. 6

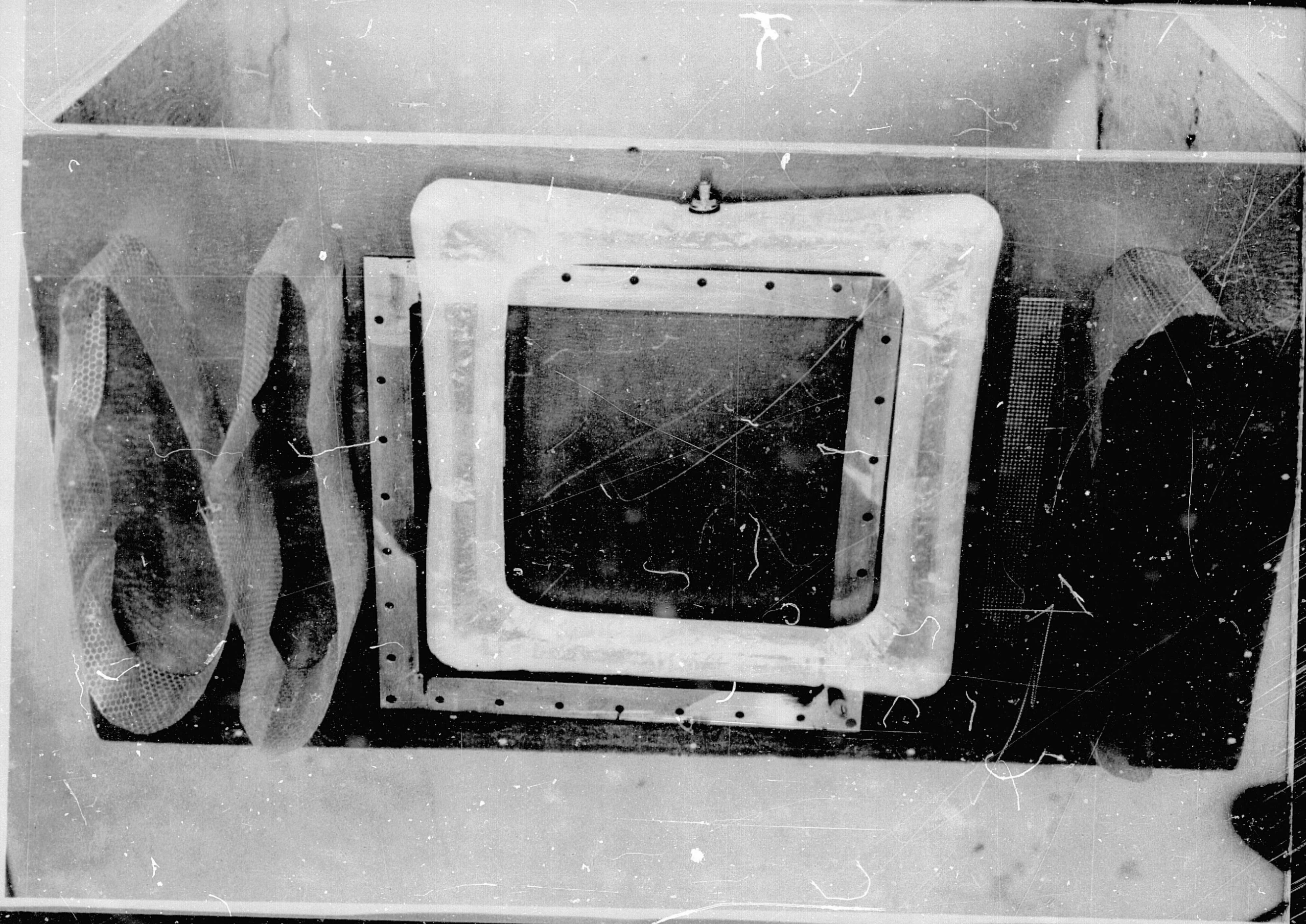
A 7-inch by 7-inch bag was fabricated from 90 per cent milled, 4-mil aluminum/0.6-mil polypropylene heat-treated advanced material and pressure-sensitive tape. It was exposed in the chamber for forty hours using the same procedure as used for the small bags in Runs No. 3 and 4. A small leak in the bag made it necessary to reinflate about every two hours. The 4-mil aluminum made the bag very rigid and it held its inflated shape well. There was no visual evidence of discoloration.

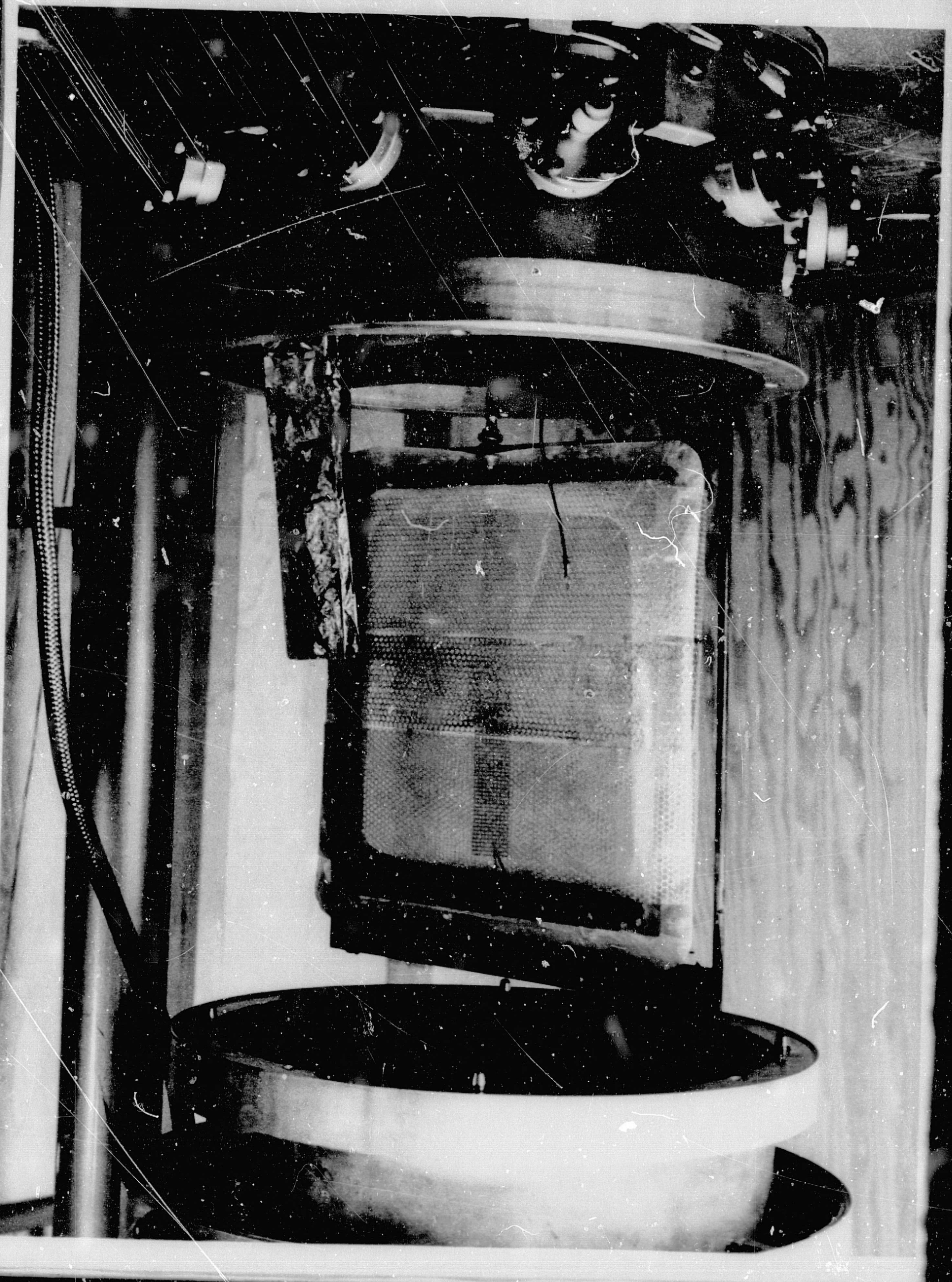
Run No. 7

A 16-hour unrestrained exposure of heat-treated X-32-F was made to check the results obtained from sample 102-44-9. The sample shrunk 1 per cent compared to 0.8 per cent shrinkage for the previous sample.

D. 50-Day Test

The samples described below were exposed in the vacuum chamber to simulated solar radiation for a total of fifty days. They were given a 50-hour restrained exposure similar to that used in the previous exploratory runs. An inflatable Mylar tube, shown in Figure 13, was fabricated so the restraint could be released without opening the chamber, which would expose the samples to oxygen. The samples were made in the form of continuous bands, Figure 14, and were slipped over the tube so they became restrained in one direction





when the tube was inflated. The restraint was released by deflating the tube through a valve.

Exposed Samples

102-67-1 4-mil aluminum/0.6-mil polypropylene. 85 per cent milled, heat-treated, adhesive removed with concentrated H_2SO_4.

102-68-2 0.5-mil aluminum/0.5-mil Mylar. 85 per cent milled, heat-treated.

102-68-3 0.35-mil aluminum/0.5-mil polypropylene (X-32-F). 78 per cent milled, heat-treated, adhesive removed.

At the end of four hours exposure it could be seen that the front of the X-32-F (102-68-3) was starting to shrink laterally in the unrestrained direction. The same type of shrinkage but much less was detected on the face of the 4-mil aluminum advanced material (102-67-1) several hours later. The 4-mil aluminum web was evidently partially restraining the plastic film. The Mylar sample 102-61-2 although discoloring rapidly was holding its shape.

The tube was deflated and the restraint released after fifty hours.

The front of the X-32-F continued to contract laterally until the plastic film melted. However, the back side of the band although only 1-1/2 inches distant retained its shape much better. (See Figure 15).

The fact that the back side of samples 102-67-1 and 102-68-2 retained their shape so well leads one to believe that restraint in

when the tube was inflated. The restraint was released by deflating the tube through a valve.

Exposed Samples

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At the end of four hours exposure it could be seen that the front of the X-32-F (102-68-3) was starting to shrink laterally in the unrestrained direction. The same type of shrinkage but much less was detected on the face of the 4-mil aluminum advanced material (102-67-1) several hours later. The 4-mil aluminum web was evidently partially restraining the plastic film. The Mylar sample 102-61-2 although discoloring rapidly was holding its shape.

The tube was deflated and the restraint released after fifty hours.

The front of the X-32-F continued to contract laterally until the plastic film melted. However, the back side of the band although only 1-1/2 inches distant retained its shape much better. (See Figure 15).

The fact that the back side of samples 102-67-1 and 102-68-2 retained their shape so well leads one to believe that restraint in

the initial stages of exposure is important. In this case, the backs of the samples were probably conditioned with reduced doses of radiation filtered through the front portion of the sample. This made it possible for the back side to resist the full amount of radiation after the front had melted away. The front of the sample however, not being conditioned with reduced radiation and not being restrained laterally, began to contract thus absorbing more radiation and becoming increasingly hotter until it degraded completely. Another factor which also contributed to the retraction of the frontof the sample band is the fact that the front was exposed to more radiation because of the reflection received from the back surface of the sample band.

The same thermocouple that was used in the exploratory runs was mounted on the front of sample 102-67-1. (See Figure 15). It was found that the temperature of the thermocouple could be varied about 15 C by varying the distance between the carbon arcs. It was also found that the temperature reached a maximum shortly after a new set of carbons were installed and then gradually decreased as the carbons were used.

The thermocouple indicated that the 50-day test was running at a considerably higher temperature than previous exploratory runs. The reflection from the back of the sample band was probably the cause.

Figure 15 shows that the seals made with Mylar tape on the back side of the bands degraded and became discolored similar to the front surface of the Mylar sample 102-68-2.

1. Shrinkage Measurements

The front of the sample bands were measured in the restrained

direction microscopically to the nearest 0.001 inch for shrinkage before and after exposure. The results are listed in Table 1. Although sample 102-67-1 only contracted 4.4 per cent in the restrained condition it contracted much more in the lateral direction.

Table 1

Shrinkage of Exposed Samples

	% Shrinkage Restrained Direction
102-67-1	4.4*
102-68-2	2.78
102-68-3	no measurement possible

* measured to nearest 1/64-inch with rule

The following Mylar samples were wrapped in aluminum foil and placed in the bottom of the chamber in the shadow of the light for shrinkage determinations:

102-68-5 0.5-mil aluminum/0.5-mil Mylar, 85 per cent milled, heat-treated.

102-68-6 0.5-mil Mylar "as received".

The amount of shrinkage that occurred in these samples was also measured microscopically to the nearest 0.001 inch.

Table 2

Shrinkage of Samples in Shadow of Light

	% Shrinkage
102-68-5	0.31
102-68-6	0.33

2. Tensile Tests

The exposed samples and those placed in the shadow of the light were tested for tensile strength and compared to their control sample. It should be pointed out that the amount of exposed sample was small making it possible to make only one Instron test in most cases.

Table 3

Tensile Strength

Exposed Sample	Side	Testing Direction	No. of Tests	Per Cent Elongation	Tensile Strength (psi)
102-67-1	Back	M	1	16	4,000
Control	----	M	1	38	17,200
102-68-2	Front	M	2	5	10,000
Control	-----	M	1	70	21,000
102-68-2	Back	M	1	10	19,100
Control	----	M	1	70	21,000
102-68-3	Back	M	1	129	23,600
Control	----	M	2	79	22,000
Samples in Foil					
102-68-5		M	1	148	31,300
Control		M	1	70	21,200
102-68-5		T	1	133	33,000
Control		T	1	116	30,800
102-68-6		M	1	51	20,800
Control		M	1	116	27,000
102-68-6		T	1	70	16,000
Control		T	1	121	18,400

The results show that a sizable percentage of tensile strength is lost when both Mylar and polypropylene are exposed

to solar radiation.

The tensile strength for both the exposed and control samples for the polypropylene/4-mil aluminum laminate 102-67-1 is noticeably low. This is believed due to strain caused by the unequal movement between the plastic film and the thick aluminum web. This theory is substantiated when compared to the higher tensile strength for sample 102-68-3 which has a slightly thinner polypropylene film and an aluminum web eight times as thin.

The high tensile strength for sample 102-68-3 can probably be explained by the fact that the tensile test was made across the lateral shrinkage that took place. A rheological study of the exposed sample would most likely show that a 1-inch wide strip would contain more material than a sample that has not undergone shrinkage.

The tensile strength of the Mylar advanced material 102-68-5 that was placed in the shadow of the arc seems to have increased quite significantly. A possible explanation lies in the fact that Mylar loses moisture in a vacuum. The moisture loss may have changed the properties of the plastic film to the point that the aluminum and the plastic are more compatible and being better matched tend to enhance the strength of the laminate.

The sample of "as received" Mylar 102-68-6 indicates that the loss of moisture in unlaminated Mylar normally lowers the tensile strength.

The change in the tensile strength of Mylar with increasing amounts of exposure to solar radiation is given in Figure 16. Although the curve consists of only four points it can be used as a qualitative guide.

3. Thermal Study

The samples of advanced material that were exposed for fifty days were analyzed to determine their thermal properties. The resulting values were used to calculate theoretical balloon temperatures using a method developed by Richard LaSell of the G. T. Schjeldahl Company and described in Figure 17.

4. Determination of Thermal Properties

Measurement of the thermal radiation properties of semi-transparent materials is complicated by the fact that absorption, transmission, and reflection are all involved. A single measurement cannot lead to a knowledge of all three properties. Since the plastic film of interest is very thin and quite transparent, the reflection can be estimated as shown in the discussion below. The spectral transmission can be readily measured on a standard spectrometer. Total transmittance can then be computed from the spectral transmittance.

The total transmittance is defined as the ratio of the energy transmitted to that incident on a surface (Kirchoff's law).

$$\tau = \frac{\int_0^\infty \tau_\lambda J_\lambda \, d\lambda}{\int_0^\infty J_\lambda \, d\lambda} \qquad (1)$$

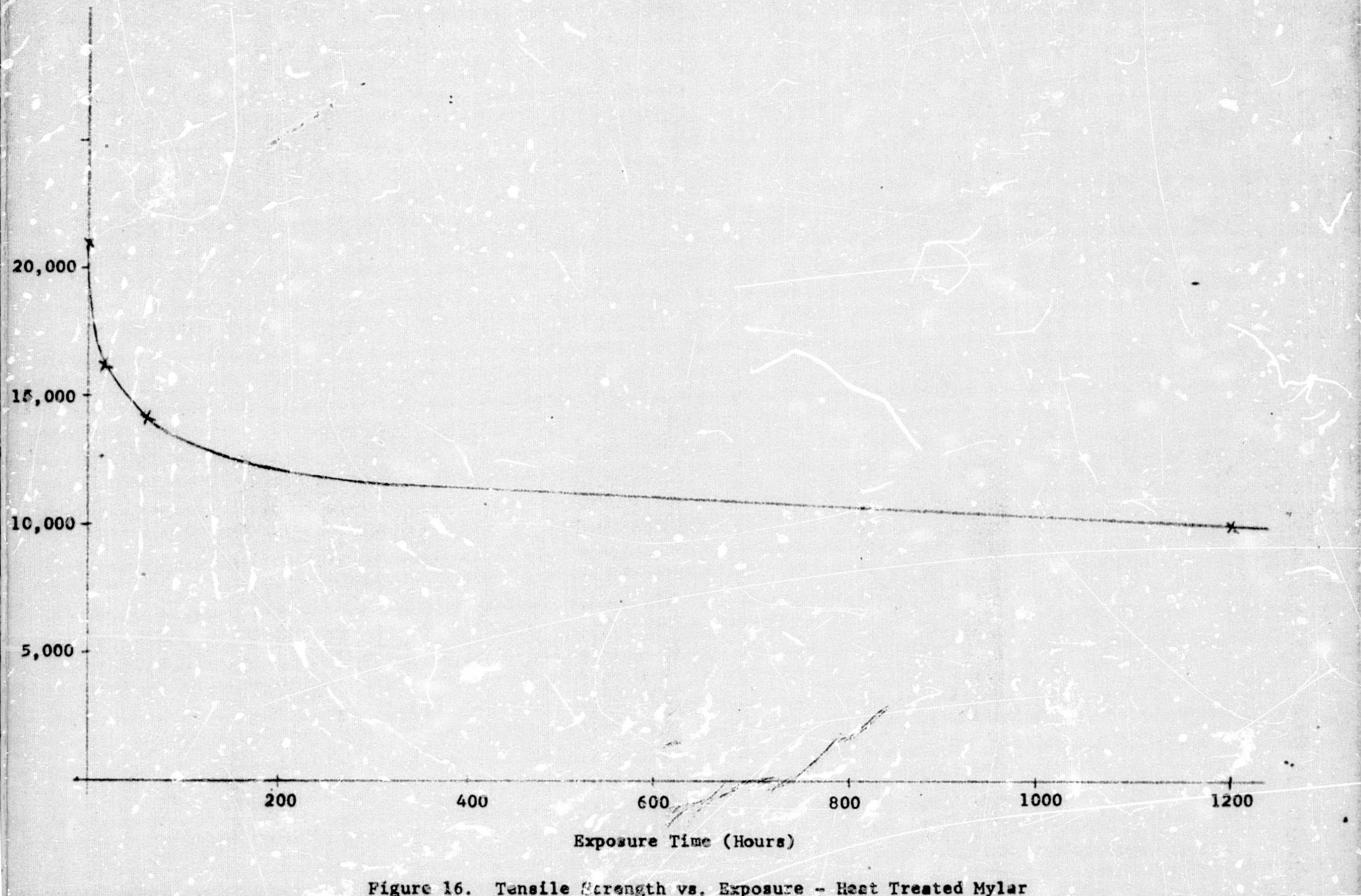


Figure 16. Tensile Strength vs. Exposure - Heat Treated Mylar

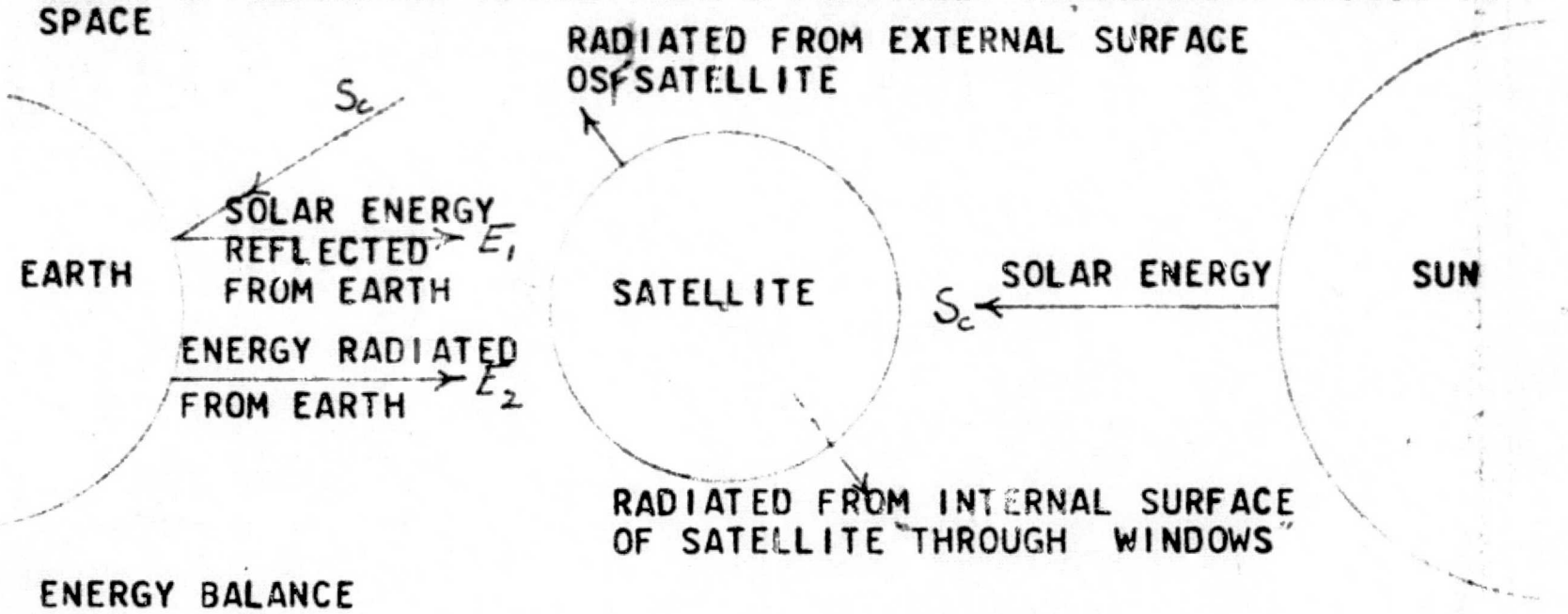
MEAN EFFECTIVE RADIAN
FOR A TRANSPAREN
(BY RICHARD

I ASSUMPTIONS:

1. BECAUSE OF LOW ABSOLUTE PRESSURE TRANSFER OF ENERGY TO AND FROM AN OBJECT IN SPACE IS ACCOMPLISHED SOLELY BY RADIATION. THERMA ENERGY TRANSFER BY CONDUCTION AND CONVECTION IS NEGLIGIBLE.

2. NO PHYSICAL TRANSFER OR CHEMICAL CHANGES WHICH MIGHT BE ACCOMPANIED BY EVOLUTION OR ABSORPTION OF HEAT ARE IN PROGRESS.

II MODES OF RADIATION TO AND FROM A PARTIALLY TRANSPARENT OBJECT IN SPACE

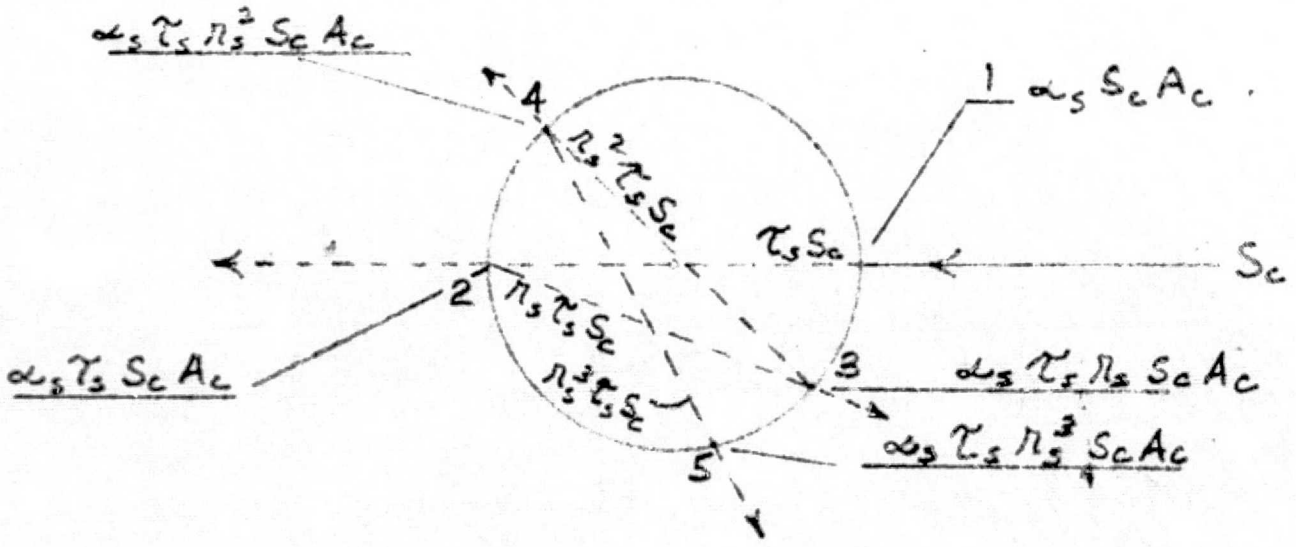


III ENERGY BALANCE

1. AT THE EQUILIBRUM TEMPERATURE THE FOLLOWING IS TRUE FOR THE SATELLITE RATE OF ENERGY ABSORPTION = RATE OF ENERGY RADIATION

2. THE SOURCES OF ENERGY TO BE ABSORBED ARE:
   E_1 SOLAR ENERGY REFLECTED FROM EARTH (SEE NASA D 1099)
   E_2 ENERGY RADIATED FROM EARTH (SEE NASA D 770)
   S_c SOLAR ENERGY

3. ABSORPTION MODEL
EACH OF THE THREE MODES OF ENERGY AVAILABLE FOR ABSORPTION (E_1 , E_2 and S_c) ARE INVOLVED IN ABSORPTION, TRANSMISSION, AND REFLECTION PROCESSES AS SHOWN BY THE FOLLOWING FOR S :



BY SUMMATION OF THE α_s TERMS

$$S_c(\text{ABSORBED}) = \alpha_s S_c A_c \left[1 + \tau_s (1 + \rho_s + \rho_s^2 + \rho_s^3 + \cdots)\right] = \alpha_s S_c A_c \left[1 + \tau_s \left(\frac{1}{1-\rho_s}\right)\right]$$

TEMPERATURE DERIVATION
SPHERE IN SPACE
LASELL)

4. THEREFORE, THE TOTAL ENERGY ABSORBED BECOMES

$$\Sigma E(\text{ABSORBED}) = \alpha_s S_c A_c \left[1 + \tau_s\left(\frac{1}{1-\pi_s}\right)\right] + \alpha_s E_1 A_c \left[1 + \tau_s\left(\frac{1}{1-\pi_s}\right)\right] + \alpha_i E_2 A_c \left[1 + \tau_i\left(\frac{1}{1-\pi_i}\right)\right]$$

5. EMISSION MODEL

ENERGY IS EMITTED FROM THE SPHERE FROM BOTH INSIDE AND OUTSIDE. THE INSIDE RADIATION IS ATTENUATED BY MULTIPLE REFLECTIVY, ABSORPTION, AND TRANSMISSION IN A MANNER SIMILAR TO THE ABSORPTION MODEL.

ENERGY EMITTED FROM EXTERNAL SURFACE = $\sigma \varepsilon_i A_s T^4$

ENERGY EMITTED FROM THE SPHERE AS THE RESULT OF THE INTERNAL RADIATION IS DEVELOPED SIMILAR TO THE ABSORPTION MODEL $= \sigma \varepsilon_i A_s T^4 \tau_i\left(\frac{1}{1-\pi_i}\right)$

$$\Sigma E(\text{EMITTED}) = \sigma \varepsilon_i A_s T^4 \left[1 + \tau_i\left(\frac{1}{1-\pi_i}\right)\right]$$

6. MEAN EFFECTIVE RADIANT TEMPERATURE:

$$\Sigma E(\text{ABSORBED}) = \Sigma E(\text{EMITTED})$$

SOLUE FOR T_{MER}^4

$$T_{MER}^4 = \frac{A_c}{\sigma \varepsilon_i A_s} \left\{ \frac{\alpha_s \left[1 + \tau_i\left(\frac{1}{1-\pi_s}\right)\right](S_c + E_1) + \alpha_i E_2 \left[1 + \tau_i\left(\frac{1}{1-\pi_i}\right)\right]}{1 + \tau_i\left(\frac{1}{1-\pi_i}\right)} \right\}$$

SYMBOLS

S_c	SOLAR ENERGY FROM SUN
E_1	SOLAR ENERGY REFLECTED FROM EARTH
E_2	INFRARED ENERGY RADIATED FROM EARTH
α_s	SOLAR ENERGY ABSORPTION
α_i	INFRARED ENERGY ABSORPTION
τ_s	SOLAR ENERGY TRANSMISSION
τ_i	INFRARED ENERGY TRANSMISSION
π_s	SOLAR ENERGY REFLECTION
π_i	INFRARED ENERGY REFLECTION
ε_i	INFRARED EMISSIVITY
A_c	CROSS SECTIONAL AREA OF SPHERE
A_s	AREA OF SPHERE

-)7(1)

FIGURE 17

Schematically this can be shown in Figure 18.

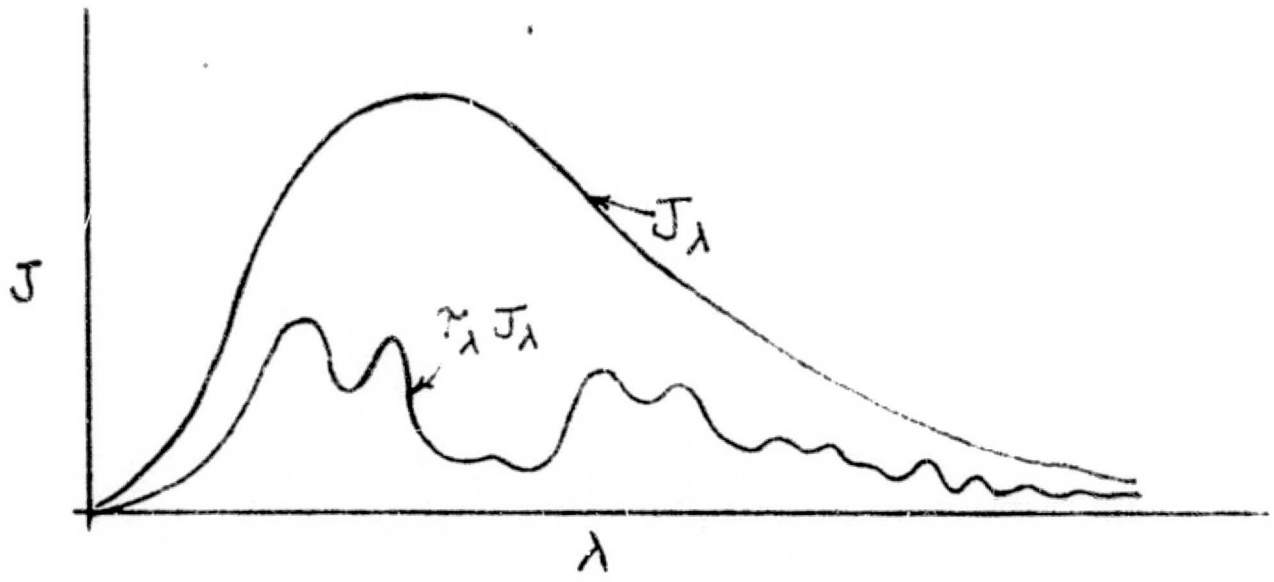


Figure 18
Distribution of Transmitted Energy

The term J_λ, represents the spectral distribution of energy from a blackbody at the temperature of the source of radiant energy and the product of the spectral transmittance times the spectral distribution, $\tau_\lambda J_\lambda$, represents the spectral distribution of the energy transmitted. The total transmittance is then equal to the ratio of the area under the curve $\tau_\lambda J_\lambda$ divided by the energy under the curve of J_λ.

If solar properties are desired, a blackbody distribution curve of 10,800 R (the apparent blackbody temperature of the surface of the sun) is used. The infrared properties applicable to lower temperature radiation are computed from a blackbody curve at the temperature of interest. The total transmittance, absorptance and reflectance for incident energy of any distribution can be calculated for a surface at a given temperature

from spectral data measured at that temperature.

Dunkle[1] has presented a convenient numerical procedure for making the integrations indicated in Equation 1 above. The calculation is carried out with the aid of a table. The table is described in his paper.

The Dunkle method was used to determine the solar transmittance, the solar reflectance and the infrared transmittance of the samples of advanced materials that were exposed for fifty days.

A Beckman DK-2A Spectrophotometer which operates in a range of 0.2 to 2.8 microns was used to measure solar transmission using a magnesium oxide standard. The solar reflection was determined on the same instrument by backing the sample with copper, coated with black Ebonal "C", which absorbed the radiation transmitted through the plastic windows.

When the composite samples were placed in the spectrophotometer, it was found that the percentage of light transmission could be varied by moving the samples. This was caused by the variation in the amount of the aluminum web in the light beam.

When the transmission curve was started the sample was moved several times until an average value was obtained.

A Perkin-Elmer 137 spectrophotometer operating in a range of 2.5 to 15 microns was used to measure the infrared transmission.

(1) R. V. Dunkle, "Thermal Radiation Tables and Applications", Trans. of ASME, 1954.

With the above-measured values for the composite material, calculation of the theoretical balloon temperatures is now possible if the infrared reflection of the plastic film and the solar reflection of the uncoated aluminum film can be determined.

The solar reflection of the uncoated aluminum foil was determined with the Beckman spectrophotometer. The Ebonal "C"-coated copper was not needed because the transmission in this case is zero.

The solar reflection of the plastic portion of the sample was estimated by using the following equation(1) by Frensel.

$$\rho = \left(\frac{n-1}{n+1}\right)^2 \qquad (2)$$

ρ = reflectivity

n = refractive index

The index of refraction of polypropylene as published in Modern Plastics Encyclopedia, Properties Chart, 1964 is $n = 1.49$ which results in a reflectivity of 3.9 per cent for normal radiation.

In the case of transparent materials, reflection occurs from both surfaces. The reflectance of such a surface is given by(2)

$$r = \rho + \frac{\left[(1-\rho)^2 \left(\rho\, e^{-2KC}\right)\right]}{1 - \rho\, e^{-2KC}} \qquad (3)$$

(1) Gubareff, Janssen, Thorborg, Thermal Radiation Properties Survey, Honeywell Research Center, 1961, p 13.

(2) Eckert, E.R.G., Heat and Mass Transfer, 2nd ed, McGraw-Hill, 1959, p 380.

If the material is thin and the absorption coefficient, K , is small as is the case for transparent materials, the equation reduces to

$$r = 2\rho\left(\frac{1}{1+\rho}\right) \qquad (4)$$

For the above case, (ρ = 3.9%) the reflectance is 7.5 per cent.

The refractive index of polypropylene is 1.49 at a wavelength of 0.589 μ . A smooth homogeneous film would therefore be expected to reflect 7.5 per cent at this wavelength. We cannot be certain of the wavelength dependence of the refractive index; however, since the above calculation is valid near the peak of the solar distribution curve, it would appear that an estimated solar reflectance of 5 per cent would be conservative. The infrared reflectance is much more uncertain. In the spectral regions where absorption bands occur and the plastic is opaque, the reflectance is equal to one minus the emittance. It would appear that here also an estimate of 5 per cent for the infrared reflectance of the plastic film would be conservative and would lead to a good estimate of the maximum temperature.

In the present case the solar reflectance of the plastic film could be calculated when the infrared reflection was estimated at 5 per cent.

The remainder of the solar values needed for the balloon temperature calculation were determined as follows:

The solar absorption (X_s) of the composite was determined by difference, since the sum of the transmission (τ_s), reflection (W_s) and absorption (X_s) equals unity.

$$X_s = 1.0 - \tau_s - W_s \qquad (5)$$

The solar reflection (ρ_{as}) curve of the uncoated, unmilled aluminum foil was measured on the Beckman spectrophotometer and the reflectance was determined by the Dunkle method.

The value of the reflectance (ρ_{as}) permits the calculation of the solar absorption (α_{as}) of the aluminum because the transmission in this case is zero.

$$\alpha_{as} = 1.0 - \rho_{as} \qquad (6)$$

The solar absorption (α_{ps}) of the plastic film can be calculated using the absorptions of the composite and aluminum. Let P = fraction of composite surface that is aluminum.

$$X_s = \alpha_{ps}(1-P) + \alpha_{as}(P) \qquad (7)$$

$$\alpha_{ps} = \frac{X_s - \alpha_{as}(P)}{(1-P)} \qquad (8)$$

The solar reflection (ρ_{ps}) of the plastic film can then be calculated by: $\tau_{ps} + \rho_{ps} + \alpha_{ps} = 1.0$ (9)

$$\rho_{ps} = 1.0 - \tau_{ps} - \alpha_{ps} \qquad (10)$$

The remainder of the infrared values needed were determined as follows:

The infrared transmission (τ_{pi}) of the plastic film

P = per cent of surface covered by aluminum

τ_i = infrared transmission of the composite sample.

$$\tau_{pi} = \frac{\tau_i}{(1 - P)} \qquad (11)$$

The infrared reflection (ρ_{pi}) of the plastic film was estimated by the method described before.

The infrared absorption (ϵ_{pi}) which equals the emissivity was calculated using the known values for reflection and transmission.

$$\tau_{pi} + \rho_{pi} + \epsilon_{pi} = 1.0 \qquad (12)$$

$$\epsilon_{pi} = 1.0 - \rho_{pi} - \tau_{pi} \qquad (13)$$

The infrared reflection (ρ_{ai}) of the aluminum was calculated knowing that the transmission is zero and that the emissivity or absorption is equal to 5 per cent.*

$$\rho_{ai} = 1.0 - .05 = .95 \qquad (14)$$

The infrared absorption (X_i) of the composite can now be calculated using known values. Let F = per cent aluminum.

$$X_i = V_i = \alpha_{pi}(1-F) + \alpha_{ai}(F) \qquad (15)$$

* Taylor, C. S. and Edwards, J. D., "Some Reflections on Radiation Characteristics of Aluminum," Heating, Piping and Air-Conditioning, 11, 59-63 (1939).

The infrared reflection (W_i) of the composite can be calculated by difference since

$$\tau + \rho + \alpha = 1.0 \tag{16}$$

$$W_i = 1.0 - \tau_i - X_i \tag{17}$$

The thermal values are summarized in Table 4.

The theoretical balloon temperature calculations for the front portion of the Mylar sample 102-68-2 are given in Figure 19 and Table 5 summarizes the calculated temperatures for all exposed samples.

The results indicate that the polypropylene advanced materials have retained their ability to transmit solar radiation as indicated by low mean and hot spot temperatures. Although the calculations are based on the back side of the samples consideration should be given to the fact that the front of sample 102-68-3 completely contracted quite early in the test exposing the back side to the full effects of the radiation.

The Mylar temperatures are considerably higher however not excessive.

Table 4

Thermal Values

(50-Day Test)

		* 102-67-1		102-68-2				102-68-3	
		Control	Back	Control	Front	Back	Seal	Back	Seal
COMPOSITE	τ_s Solar Transmission	.71	.70	.62	.42	.60	.53	.62	
	W_s Solar Reflection	.18	.18	.20	.14	.18	.21	.27	
	X_s Solar Absorption	.11	.12	.18	.44	.22	.26	.11	
	τ_L Infrared Transmission	.54	.57	.37	.38	.38	.29	.58	.29
	W_L Infrared Reflection	.19	.18	.17	.17	.17	.17	.16	
	X_L Infrared Absorption	.27	.25	.46	.45	.45	.54	.26	
PLASTIC	τ_{ps} Solar Transmission	.83	.82	.73	.49	.71	.62	.82	
	ρ_{ps} Solar Reflection	.09	.09	.11	.04	.08	.12	.10	
	α_{ps} Solar Absorption	.08	.09	.16	.47	.21	.26	.08	
	τ_{pL} Infrared Transmission	.64	.67	.44	.45	.45	.34	.68	
	ρ_{pL} Infrared Reflection	.05	.05	.03	.03	.03	.03	.05	
	ϵ_{pL} Infrared Absorption	.31	.28	.53	.52	.52	.63	.29	
		---	---	---	---	---	---	---	---
ALUMINUM	ρ_{as} Solar Reflection	.74	.74	.74	.74	.74	.74	.74	
	α_{as} Solar Absorption	.26	.26	.26	.26	.26	.26	.26	
	ρ_{aL} Infrared Reflection	.95	.95	.95	.95	.95	.95	.95	
	ϵ_{aL} Infrared Absorption	.05	.05	.05	.05	.05	.05	.05	

* 102-67-1 4 mil aluminum/0.6 mil polypropylene, 85% milled, heat treated, adhesive removed.
102-68-2 0.5 mil alum./0.5 mil Mylar, 85% milled, heatttreated
102-68-3 0.35 mil alum./0.5 mil polypropylene (X-32-F) 78% milled, heat treated, adhesive removed.

CALCULATION OF MEAN RADIANT TEMPERATURE = T_{MER}

$$T_{MER}^4 = \frac{1}{4\sigma V_1}\left(\frac{X_s[S_c+E][1+\tau_{ps}\left(\frac{1-P}{1-W_s}\right)]+}{1+\tau_{pi}(}\right.$$

$$= \frac{1}{4(5.67\times10^{-5})(.45)}\left(\frac{.44[(.35+.6325)10^6][1+}{1+}\right.$$

$T_{MER}^4 = .0918\times10^{11}$ $\qquad$ $T_{MER} = 310$

CALCULATION OF HOT SPOT TEMPERATURE, PLASTIC = T_{HSP}

$$T_{HSP}^4 = \frac{1}{2\sigma\varepsilon_{pi}}\left\{S_c\alpha_{ps}[1+\tau_{PS}W_s\left(\frac{1-P}{1-W_s^2}\right)]-\right.$$

$$= \frac{1.35\times10^6(.45)[1+.49(.14)\left(\frac{1-.15}{1-.14^2}\right)+.6325\times10^6(}{}$$

$T_{HSP}^4 = .161\times10^{11}$ $\qquad$ $T_{HSP} = 357$

THERMAL CALCULATION FOR TRANSPARENT SPHERE IN SPACE

$$\left(\frac{E_2 x_i \left[1 + \tau_{pi} \left(\frac{1-P}{1-w_i} \right) \right]}{\left(\frac{1-P}{1-w_i} \right)} \right) \qquad (1).$$

$$\left(\frac{.49\left(\frac{1-.15}{1-.14}\right) + .108\times10^{-8}(.45)\left[1+.45\left(\frac{1-.15}{1-.17}\right)\right]}{(.45)\left(\frac{1-.15}{1-.17}\right)} \right)$$

$T_{MER} = 37\,^{\circ}C$

$$+ E_1 \alpha_{ps} \tau_{ps} \left(\frac{1-P}{1-w_s^2}\right) + E_2 \tau_{pi} e_{pi} \left(\frac{1-P}{1-w_i^2}\right) \Bigg\} + \frac{x_i T_{MER}^4}{2(1-w_i^2)}$$

$$\frac{(.45)(.49)\left(\frac{1-.15}{1-.14^2}\right) + .108\times10^{-8}(.45)(.52)\left(\frac{1-.15}{1-.14^2}\right)}{} + \frac{.43\,(.094\times10^{-8})}{2\,(1-.14^2)}$$

$T_{HSD} = 84\,^{\circ}C$

CONDITIONS FOR CALCULAT

(SAMPLE 102-68-2, EXPO
.5 MIL ALUMINUM .5 M
85% MILLED, HEAT TREA
ALBEDO
ALTITUDE
ATTITUDE
SOLAR CONSTANT
FRACTION ALUMINUM
REFLECTION FROM EARTH
(NASA D 1099)
RADIATION FROM EARTH
(NASA D 770)
BOLTZMANN CONSTANT

PLASTIC PROPERTIES

SOLAR ABSORPTION
INFRARED ABSORPTION
SOLAR REFLECTION
INFRARED REFLECTION
SOLAR TRANSMISSION
INFRARED TRANSMISSIO

ALUMINUM PROPERTIES

SOLAR ABSORPTION
INFRARED ABSORPTION
SOLAR REFLECTION
INFRARED REFLECTION

COMPOUNDED PROPERTIES

SOLAR ABSORPTION

INFRARED ABSORPTION X

SOLAR REFLECTION

INFRARED REFLECTION

FIGURE 19

HERMAL CALCULATION FOR TRANSPARENT SPHERE IN SPACE

$$+ \frac{\tau_{pi}\,\varepsilon_{pi}\left(\frac{1-P}{1-W_i}\right)}{\quad}\Bigg] \qquad (1)$$

$$\frac{\left(\frac{1-.15}{1-.14}\right)}{\left(\frac{1-.15}{1-.17}\right)} + .108\times10^{-6}(.45)\left[1+.45\left(\frac{1-.15}{1-.17}\right)\right]$$

$$T_{MER} = 37\,^{\circ}C$$

$$\tau_{ps}\left(\frac{1-P}{1-W_s^2}\right) + E_2\,\tau_{pi}\,\varepsilon_{pi}\left(\frac{1-P}{1-W_i^2}\right)\Bigg\} + \frac{X_i\,T_{MER}^4}{2(1-W_i^2)}$$

$$\frac{\left(\frac{1-.15}{1-.14^2}\right) + .108\times10^{-6}(.45)(.52)\left(\frac{1-.15}{1-.145^2}\right)}{} + \frac{.43\,(.094\times10^{-11})}{2\,(1-.145^2)}$$

$$T_{MSD} = 84\,^{\circ}C$$

FIGURE 19

CONDITIONS FOR CALCULATION:

(SAMPLE 102-69-2, EXPOSED 50 D
.5 MIL ALUMINUM .5 MIL MYLAR
85% MILLED, HEAT TREATED

ALBEDO	= 0.8
ALTITUDE	= 17
ATTITUDE	IN
SOLAR CONSTANT	S_c = 1.3
FRACTION ALUMINUM	P = .1
REFLECTION FROM EARTH (NASA D 1099)	E_1 = 63
RADIATION FROM EARTH (NASA D 770)	E_2 = 10
BOLTZMANN CONSTANT	σ = 5.

PLASTIC PROPERTIES

SOLAR ABSORPTION	α_{ps} =
INFRARED ABSORPTION	ε_{pi} =
SOLAR REFLECTION	ρ_{ps} =
INFRARED REFLECTION	ρ_{pi} =
SOLAR TRANSMISSION	τ_{ps} =
INFRARED TRANSMISSION	τ_{pi} =

ALUMINUM PROPERTIES

SOLAR ABSORPTION	α_{as} =
INFRARED ABSORPTION	ε_{ai} =
SOLAR REFLECTION	ρ_{as} =
INFRARED REFLECTION	ρ_{ai} =

COMPOUNDED PROPERTIES

SOLAR ABSORPTION	$X_s = \alpha$
	= .4
	= .5
INFRARED ABSORPTION	$X_i = V_i \equiv \varepsilon$
	= .5
	= .4
SOLAR REFLECTION	$W_s = \rho$
	= .8
	= .1
INFRARED REFLECTION	$W_i = \rho$
	= .9
	= .1

DAYS
(DUPONT, TYPE A))

5
00 Miles
LINE
353 x 10^4 ERG/CM^2 sec
5
25 x 10^4 ERG/CM^2 sec
.8 x 10^4 ERG/CM^2 sec
67 x 10^-5 ERG/CM^2 sec

.47
.52
.04
.03
.49
.45

.26
.05
.74
.95

$\alpha_{ps}(1-P) + \alpha_{as} P$
$.47(.85) + .26(.15)$
.44

$\alpha_{pi}(1-P) + E_{ai} P$
$.52(.85) + .05(.15)$
.45

$\rho_{ps}(1-P) + \rho_{as} P$
$.04(.85) + .74(.15)$
.14

$\rho_{pi}(1-P) + \rho_{ai} P$
$.03(.85) + .95(.15)$
.17

Table 5

Calculated Balloon Temperatures

		Mean Radiant Temp °C	Hot Spot Plastic °C
102-67-1			
Back	Polypropylene 4-mil Al	-6	15
102-68-2			
Front (Mylar)		37	84
Seal (Back)			39
102-68-3			
Back (X-32-F)		-10	9